Indian J. Phys. **74B** (5), 383–386 (2000)

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I J P B
an international journal

Study of coronal mass ejections and coronal holes associated mid-latitude geomagnetic storms observed during 1986-1996

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Received 10 January 2000, accepted 9 May 2000

Abstract : A set of 103 mid-latitude large geomagnetic storms associated with increase in planetary index ($K_p \geq 7$), which occurred during 1986-96, has been analyzed. The yearly occurrence of these selected geomagnetic storms varies with the annual mean sunspot number (SSN) having some peculiarities. However, the number of observed storms is a maximum during solar maximum period (1989-91). The occurrence of recurrent and non-recurrent types of mid-latitude large geomagnetic storms, during maximum and minimum phases of solar cycle 22 and their associated solar causes have also been analyzed.

Keywords : Coronal mass ejections, geomagnetic storms, sunspot number

PACS Nos. 92 60 Qx, 96 60.Pb

Geomagnetic disturbances are global disturbances of the earth's magnetic field, known as "geomagnetic storms", and can be classified into many alternate ways such as their distribution in space, intensity, development in time and frequency of occurrence. On the basis of 27-days rotation period of the Sun, the geomagnetic storms may be classified into two basic kinds : sporadic (non-recurrent) and recurrent. A class of geomagnetic disturbances with the mean solar rotation period (27-days), recurs over several solar rotations. Bartels [1] postulated the so-called solar M-region as the source of these recurrent disturbances. We have classified the geomagnetic storms on the basis of their occurrence in space, termed as equatorial region, mid-latitude and polar region geomagnetic storms. There is a variety of development of geomagnetic disturbances and their several solar sources of origin, such as coronal mass ejections (CMEs), coronal holes (CHs), solar flares, eruptive prominences, disappearing filaments, metric type radio-bursts, as have been suggested by a number of researchers. Two types of solar wind streams, termed as corotating flows and transient disturbances are also associated with solar source activities and geomagnetic disturbances. The corotating flows are magnetically open, long-lasting, high speed flows in quiescent solar wind, usually originating in coronal holes and exhibiting an apparent tendency to recur with the 27-day rotation period of the Sun [2]. Nolte *et al* [3] have shown that coronal holes coincide with high velocity streams in the solar wind and they produce recurrent geomagnetic disturbances. Sheeley and Harvey [4] have shown a relation between the position of coronal holes, the interplanetary magnetic field direction, the solar wind speed, and the magnitude of disturbances in the earth's magnetic field. Sheeley and Harvey [5,6] have shown the long-term evolution of coronal holes, high-speed solar wind streams and geomagnetic enhancement, during the period 1973-79 and concluded that coronal holes were indeed in solar origin of recurrent, high-speed solar wind streams, observed in the ecliptic plane at 1 AU. Hewish and Bravo [7] have shown that the solar source regions were always accompanied by coronal holes and suggested that the transient activity at hole boundaries could produce interplanetary shocks. The second rather low-speed flow (transient disturbances) arises from the transient eruption of close-field solar regions and is mostly associated with coronal mass ejections. CMEs are now considered by many authors as the solar origin of interplanetary disturbances and transient disturbances in solar wind that causes large non-recurrent geomagnetic storms. It is believed that the CMEs can be produced by restructuring of corona, and can significantly perturb the solar wind and disrupt the earth's environment [8,9]. A good association of equatorial region large geomagnetic disturbances with CMEs and large solar flares, during solar cycle 22, were indicated in our previous works [10–12]. Currently, it is believed that two types of solar activity termed as coronal mass ejections and coronal holes are the most violent features on solar atmosphere, and generally large geomagnetic disturbances are caused by these solar activities. These solar activities arise through two kinds of solar wind streams termed as transient disturbances and corotating flows. A basic difference between CMEs and CHs associated phenomena is that the CMEs arise due to high solar activity and are associated with transient disturbances arising from solar activity in magnetically closed regions, and mainly produce interplanetary disturbances that cause large non-recurrent geomagnetic storms on earth. On the other hand, coronal holes are associated with corotating flows in solar wind streams, arising from magnetically open regions and could produce interplanetary disturbances that cause recurrent geomagnetic disturbances on earth. Both solar activities (CMEs and CHs), can produce interplanetary (IP) shocks that are responsible for geomagnetic disturbances, but they appear in regions of lower (less than 30) and higher (more than 30°) latitudes In this work, an attempt is made to examine the association of non-recurrent and recurrent mid-latitude geomagnetic storms with CMEs and CHs alongwith solar cycle variation of mid-latitude large geomagnetic storms, during the period 1986-96, which covers two extreme phases of complete solar cycle 22.

The average behaviors of the geomagnetic field disturbances on mid-latitude are available through measurements of planetary K_p and A_p indices. The values of K_p index are available on 3-hour interval logarithmic scale, whereas planetary index A_p represents the degree of global geomagnetic variability of each day. The K_p index is defined as the arithmetic mean value of the K_s values at 13 standard observatories and express the degree of global geomagnetic activity over the whole earth. So, we have taken planetary index K_p for the counting of mid-latitude geomagnetic storms, because its values are available on short-term 3-hour scale and represent the occurrence of storms in the world wide mid-latitude. In the present analysis, we have compiled all those mid-latitude geomagnetic storms, that are associated with an increase in the value of planetary index K_p more than 7, during the period (1986-96) to analyze their association with two main solar transients CMEs and CHs. The annual mean value of SSN, 3-hour K_p values, data of coronal mass ejections and coronal holes have been obtained from *Solar Geophysical Data Reports (Part-I and II)* of U.S. Department of commerce, NOAA (monthly issues). A list of 103 selected mid-latitude large geomagnetic storms and their yearly occurrences are presented in Table 1.

Table 1. Yearly occurrence of mid-latitude large geomagnetic storms $K_p > 7$, observed during 1986-96

Years	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996
Number of observed storms	06	01	06	16	13	25	12	11	08	04	01

The solar cycle 22 among other 21 solar cycles, exceptionally, contains two peaks during the year 1989 and 1991. So, the maximum phase of 22nd solar cycle has been measured during the year 1989-91. The periods 1986-88 and 1992-96 have been taken respectively as ascending solar minimum and descending solar minimum periods. The associations of yearly occurrence of 103 selected mid-latitude large geomagnetic stroms with annual mean values of sunspot number (SSN) during the aforesaid period, are plotted in Figure 1. From this plot, it is found that the yearly occurrence of mid-latitude large geomagnetic storms varies

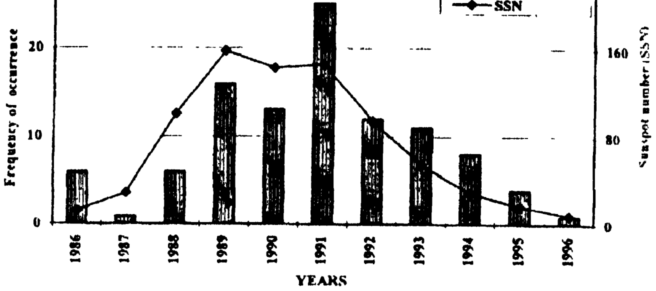

Figure 1. Plot of the frequency of occurrence histogram of 103 mid-latitude large geomagnetic storms and their association with annual mean sunspot number (SSN), during minimum and maximum phases of solar cycle 22

with annual mean sunspot number barring some peculiarities, during the year 1987 and 1991. It is also found that the number of mid-latitude large geomagnetic storms which occurred are a maximum, during the solar maximum period (1989-91). This result indicates that the yearly occurrence of geomagnetic activities varies with solar cycle barring some peculiarities and shows similar results as discussed by many researchers.

On the basis of the 27-days rotation period of the Sun, the geomagnetic storms may be classified into two kinds non-recurrent and recurrent In this communication, yearly occurrences of non-recurrent, recurrent and total number of mid-latitude large geomagnetic storms with maximum and minimum phases of solar cycle 22, are plotted in Figure 2 From this plot, it is found that the maximum number of recurrent geomagnetic storms was observed during the total solar minimum period (inclusively ascending and descending phase), while, the maximum number of non-recurrent geomagnetic storms occurred during the solar maximum phase of solar cycle 22. It is also found that 52.4% mid-latitude large geomagnetic storms were non-recurrent type and remaining 47.6% are recurrent type, during the aforesaid period. There is a concentration of 61 non-recurrent type mid-latitude large geomagnetic storms occurring during solar maximum phase, whereas 57% recurrent type mid-latitude large geomagnetic storms occurred during solar minimum phase. It is inferred that two types of solar wind streams and their occurrence in maximum and minimum phases are responsible for this. During the solar maximum period, the maximum number of non-recurrent mid-latitude geomagnetic disturbances are caused by transient disturbances in solar wind streams, whereas, in the solar minimum periods, the maximum number of recurrent geomagnetic disturbances are caused by corotating flows in solar wind streams. So, the maximum number of non-recurrent mid-latitude large geomagnetic storms occurred during solar maximum period and maximum number of recurrent mid-latitude large geomagnetic disturbances occurred during the solar minimum periods.

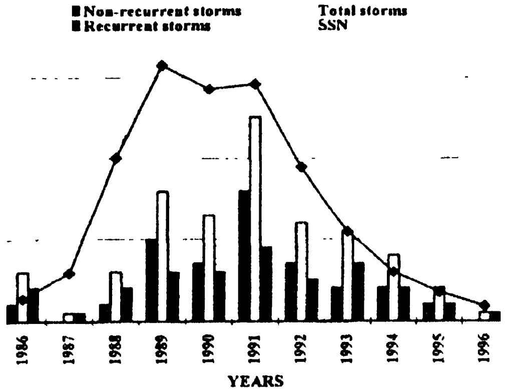

Figure 2. Plot of the frequency of occurrence histogram of non-recurrent, recurrent and total number of geomagnetic storms and their association with annual mean sunspot number (SSN), during the period 1986-96

The studies of large geomagnetic storms are most important in the field of space-weather environment. So, we have shown the association of mid-latitude large geomagnetic storms ($K_p \geq 7_-$) with two main solar transients (CMEs and CHs), which are depicted in Figure 3. From this plot, it is

Figure 3. Plot of the frequency of occurrence histogram of CMEs associated, CHs associated and total number of large geomagnetic storms ($K_p \geq 7_-$) and their associated annual mean sunspot number (SSN), during minimum and maximum phases of 11-year sunspot cycle of solar cycle 22

inferred that out of the selected 103 mid-latitude large storm events, maximum number of mid-latitude large geomagnetic storms were caused by CMEs during the maximum phase of solar activity cycle, whereas, the maximum number of mid-latitude large geomagnetic storms were associated with coronal holes during minimum phase of solar activity cycle 22. It is not essential that all mid-latitude large geomagnetic storms are caused by coronal mass ejections during solar maximum and all mid-latitude large geomagnetic storms are caused by coronal holes during solar minimum. This result shows the trend of maximum associations. It is also seen that the magnitude of storms is not associated with both solar transients (CMEs and CHs). The magnitude of storms is strongly correlated with solar wind speed, interplanetary magnetic field (IMF B) and southward directed IMFs. This phenomena is associated with electromagnetic coupling $V \cdot B_z$ of solar wind streams and IMF B with the geomagnetosphere. The southward directed IMFs provide an opportunity to enter the solar plasma and magnetic field in the geomagnetosphere. So, both kinds of solar transients (CMEs and CHs) that are associated with strong electromagnetic coupling and large values of southward directed IMFs are able to produce large geomagnetic storms.

- Yearly occurrence of mid-latitude large geomagnetic storms varies with annual mean sunspot number barring some peculiarities and the number of mid-latitude large storm events is a maximum, during the solar maximum period (1989-91).
- We have found that 61% non-recurrent type geomagnetic storms occur during the maximum phase, whereas 57% recurrent type geomagnetic storms occur during the minimum phase of solar cycle 22. So, it is concluded that the number of recurrent geomagnetic storms is higher during the solar minimum period, whereas the number of non-recurrent geomagnetic storms is higher during solar maximum period.
- Out of selected 103 mid-latitude large geomagnetic storm events, the maximum number of large storm events was caused by CMEs during maximum phase of solar activity cycle, whereas, the maximum numbers of large storm events was associated with coronal holes during the minimum phase of solar activity cycle 22.

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